

then these animals in it live longest and move very briskly : whereas on the contrary the Melt being not full ripe , we must with force press it out of the Fish , and then tis difficult to see these Animalcules alive .

A Theory of the Variation of the Magnetical COMPASS, by Mr. Ed. Halley Fellow of the R. S.

THe Variation of the Compass (by which I mean the deflection of the Magnetical Needle from the true Meridian) is of that great concernment in the Art of Navigation : that the neglect thereof, does little less than render useless one of the noblest Inventions mankind ever yet attained to. And for this cause all Ships of Consequence (especially those bound beyond the Equator) carry with them Instruments on purpose to observe this Variation : that so the course steered by the Compass, may be reduced to the true course in respect of the Meridian.

Now altho the great utility that a perfect knowledge of the Theory of the Magnetical direction would afford to mankind in general, and especially to those concerned in Sea affairs, seem a sufficient incitement to all Philosophical and Mathematical heads, to take under serious consideration the several *Phænomena*, and to endeavour to reconcile them
by

by some general rule : yet so it is ; that almost all the Authors , from whom a discourse of this kind ought to have been expected , pass by in silence the difficulties they here encounter. And those that mention this Variation : by affirming it to proceed from causes altogether uncertain (as are the casual lying of Iron mines and Loadstones in in the Earth) put a stop to all further contemplations and give discouragement to those that would otherwise undertake this Enquiry. 'Tis true that not long since one Mr. Bond, an old Teacher of Navigation , put forth a small Treatise wherein he pretends to calculate the Variation : but he limits his Hypothesis to the City of *London* , affirming himself (as he had a great deal of reason ,) that the same *Calculus* is not sufficient for other places : whereby it appears that his rule is far short of the so much desired general one.

Now altho (through want of sufficient observations and some other difficulties which I shall anon shew) I cannot pretend perfectly to establish the numbers and rules of a *Calculus* which shall precisely answer to the Variations of all parts of the World : yet I suppose it will not be unacceptable to the curious to propose something of a light into this abstruse mystery ; which, if no other, may have this good effect, to stir up the Philosophical *Genij* of the age to apply themselves more attentively to this useful speculation. But before I proceed , 'twill be necessary to lay down the grounds upon which I raise my Conclusions ; and at once to give a Synopsis of those Variations which I have reason to look upon as sure , being mostly the observations of persons of good skill and Integrity.

(210)

A TABLE OF VARIATIONS.

<i>Names of Places.</i>	<i>Longitude. from Lond.</i>	<i>Latitude.</i>	<i>Anno Dom.</i>	<i>Variation Observed.</i>
	gr °	° ' N		° ' E. W.
London		51. 32 N	1580 1622 1634 1672 1683	11 15 E. 6 0 E. 4 5 E. 2 30 W. 4 30 W.
Paris	2. 25 E	48. 51. N	1640 1666 1681	3 00 E. 0 0 2 30 W.
Uraniburg	13. 0 E	55. 54 N	1672	2 35 W.
Copenhagen	12. 53 E	55. 41 N	1649 1671	1 30 E. 3 35 W.
Dantzick	19. 0 E	54. 23 N	1679	7 00 W.
Mompelien	4. 0 E	43. 37 N	1674	1 10 W.
Brest	4. 25 W	48. 23 N	1680	1 45 W.
Rome	13. 0 E	41. 50 N	1681	5 0 W.
Bayonne	1. 20 W	43. 30 N	1680	1 20 W.
Hudsons Bay	79. 40 W	51 00 N	1668	19 15 W.
In Hudsons Straights	57. 00 W	61 00 N	1668	29 30 W.
In Baffins Bay at Sir Thomas Smiths Sound	80. 00 W	78 00 N	1516	57 00 W.

Names

<i>Names of Places.</i>	<i>Longitude.</i>			<i>Latitude.</i>			<i>Anno Dom</i>	<i>Variation.</i>		
	°	'		°	'			°	'	
At Sea —————	50	0	W.	38	40	N	1682	7	30	W.
At Sea —————	31	30	W.	43	50	N	1682	5	30	W.
At Sea —————	42	0	W.	21	0	N	1678	2	40	E.
Cape St. Augustine of Brazile	35	30	W.	8	0	S	1670	5	30	E.
Cape Frio —————	41	10	W.	22	40	S.	1670	12	10	E.
At Sea off of the Mouth of the } River of Plate	53	00	W.	39	30	S.	1670	20	30	E.
At the East Entrance of Magel- } lan Straits	68	00	W.	52	30	S.	1670	17	00	E.
At the West Entrance of the } Magellans Straits	75	00	W.	53	00	S.	1670	14	10	E.
Valdivia —————	73	00	W.	40	00	S.	1670	8	10	E.
At Cape d' Agulhas —————	16	30	E.	34	50	S.	1622	2	00	W.
							1675	8	00	W.
At Sea —————	1	0	E.	34	30	S.	1675	0	0	
At Sea —————	20	0	W.	34	0	S.	1675	10	30	E.
At Sea —————	32	0	W.	24	0	S.	1675	10	30	E.
At St. Helena —————	6	30	W.	16	0	S.	1677	0	40	E.
At Ascension —————	14	30	W.	7	50	S.	1678	1	00	E.
At Johanna —————	44	00	E.	12	15	S.	1675	19	30	W.
At Mombasa —————	40	00	E.	4	00	S.	1675	16	00	W.
At Zocatra —————	56	00	E.	12	30	N.	1674	17	00	W.
At Aden, at the mouth of the } Red Sea.	47	30	E.	13	00	N.	1674	15	00	W.
At Diego Roix —————	61	0	E.	20	0	S.	1676	20	30	W.
At Sea —————	64	30	E.	0	0		1676	15	30	W.
At Sea —————	55	0	E.	27	0	S.	1676	24	00	W.
At Bombay —————	72	30	E.	19	0	N.	1676	12	00	W.
At Cape Comorin —————	76	00	E.	8	15	N.	1680	8	48	W.
At Ballasore —————	87	00	E.	21	30	N.	1680	8	20	W.
At Fort St. George —————	80	00	E.	13	15	N.	1680	8	10	W.
At the West point of Java	104	0	E.	6	40	S.	1676	3	10	W.
At Sea —————	58	00	E.	39	0	S.	1677	27	30	W.
At the Isle of St. Paul —————	72	0	E.	38	0	S.	1677	23	30	W.
At Van Diemens Land —————	142	0	E.	42	25	S.	1642	0	0	
At New Zealand —————	170	0	E.	40	50	S.	1642	9	0	E.
At Three Kings Isle in New- } Zealand	169	30	E.	34	35	S.	1642	8	40	E.
At the isle. Rotterdam in the } South Sea	184	00	E.	20	15	S.	1642	6	20	E.
on the Coast of New-Guinea	149	00	E.	4	30	S.	1643	8	45	E.
at the West point of New-Guinea	126	00	E.	0	26	S.	1643	5	30	E.

Tho I could wish we could obtain from the Spaniards what Variations they find in their Voyages from the *Mamilhas* towards *Acapulco*, thro the North part of the South Sea ; as likewise what it is at *Japan*, from the Dutch : yet, (considering the number of these observations I have collected, and that they are made in parts of the World so remote from *Europe*, and from one another (I suppose that the Theory that answers these will scarce fail in those Regions from whence we have as yet no account. But first we must make some remarks upon the foregoing Table. and First.

That in all *Europe* the variation at this time is *West*, and more in the Eastern parts thereof than the Western : as likewise that it seems throughout to be upon the increase that way-

Secondly that on the Coast of *America*, about *Virginia*, *New-England* and *New-Found land*, the Variation is likewise *Westerly* ; and that it increases all the way as you go Northerly along the Coast so as to be above 20 degrees at *New-found land*, nearly 30 gr. in *Hudsons straits*, and not less than 57. degrees in *Bassins Bay* ; also that as you sail Eastward from this coast the Variation diminishes. From these two it is a Legitimate Corollary : that *Somewhere between Europe, and the North-part of America, there ought to be an Easterly Variation, or at least no Westerly.* and so I conjecture it is about the Eastermost of the *Tercera Islands*.

3. That on the coast of *Brasile* there is East Variation which increases very notably as you go to the South-ward so as to be 12. degrees at *Cape Frio*, and over against the river of *Plate* 20 $\frac{1}{2}$ degrees : and from thence sailing south-westerly to the straits of *Magellan* it decreases 17 degrees, and at the west entrance but 14 degrees.

4. That at the Eastward of *Brasile* properly so called, this Easterly Variation decreases, so as to be very little

at *St. Helena* and *Ascension*, and to be quite gone and the Compass point true about 18 degrees of Longitude West from the Cape of *Good hope*.

5. That to the Eastward of the aforesaid places a Westward Variation begins, which reigns in the whole *Indian Sea*, and arises to no less than Eighteen degrees under the Equator it self, about the Meridian of the Northern part of *Madagascar*; and near the same Meridian but in 39. degrees South Lat. it is found full $27 \frac{1}{2}$ degrees: from thence Easterly the West Variation decreases, so as to be but little more than Eight degrees at *Cape Comorin*, and than Three degrees upon the Coast of *Java*; and to be quite extinct about the *Molucca Islands*, as also a little to the Westwards of *Van Diemens Land* found out by the Dutch in 1642.

6. That to the Eastward of the *Molucca's* and *Van-Diemens Land* in South Latitude there arises another easterly Variation, which seems not so great as the former nor of so large extent; for that at the Island *Rotterdam* it is sensibly less than upon the East Coast of *New Guinea*; and, at the rate it decreases, it may well be supposed that about 20 degrees farther East, or 225 degrees East Longitude from *London*, in the Latitude of 20 degrees South, a Westerly Variation begins.

7. That the Variations observed by the Honourable *Sr. John Norborough* at *Baldivia* and at the West entrance of the Straights of *Magellan* do plainly shew, that that East Variation noted in our third remark is decreasing apace; and that it cannot reasonably extend many degrees into the South Sea from the Coast of *Peru* and *Chili*, leaving room for a small Westerly Variation, in that tract of the un-

known World that lies in the midway between *Chili* and *New-Zealand*, and between *Hounds-Island* and *Teru*.

8. That in sailing North-west from *St. Helena* by *Ascension* as far as the Equator the Variation continues very small East, and as it were constantly the same: so that in this part of the World the Course, wherein there is no Variation, is evidently no Meridian; but rather North-west

9. That the entrance of *Hudsons Straights* and the Mouth of the River of *Plate* being nearly under the same Meridian, at the one place the Needle varies $29\frac{1}{2}$ degrees to the *West*; at the other $20\frac{1}{2}$ degrees to the *East*. This plainly demonstrates the impossibility of reconciling these Variations by the Theory of Bond: which is by two *Magnetical Poles* and an *Axis*, inclined to the *Axis* of the *Earth*; from whence it would follow, that under the same Meridian the Variation should be in all places the same way.

These things being premised may serve as a sure foundation to raise the superstructure of a Theory upon. But first it would not be amiss to shew hereby the mistake of *Gilbert* and *Des-Cartes*: The first whereof supposes: that the *Earth* it self being in all its parts *Magnetical*, and the *Water* not; wheresoever the *Land* is, thither also should the Needle turn, as to the greater quantity of *Magnetical* matter. But this in many instances is not true; but most remarkably upon the Coast of *Brasile*: where the Needle is so far from being attracted by the *Land*, that it turns the quite contrary way, leaving the Meridian to lye *N B E*, which is just along the Coast. As to the position of *Des Cartes*, that the *Iron* and *Loadstones* hid in the Bowels of the *Earth* and the Bottom of the *Sea* maybe the Causes that the Needle varies; If we consider for how great a part of the *Earths* surface

ex gr. in the whole Indian Sea, the Needle declines the same way, and that regularly : twill follow that the attracting Substance that occasions it, must be very far distant. Now by Experience we find the little force that Iron Guns have upon the Compass in ships (their vertue, tho they be demi-cuiverin , or greater Cannon , being not perceptible at Four or Five yards distance) and the Experiments now before the *Royal Society* do plainly shew , how little a Magnetism there is in most crude Iron Ores : what quantity thereof must be then supposed to make so powerfull a diversion at Two or Three Thousand miles distance ? Yet I cannot deny that in some places near the shore , or in shoal water , the Needle may be irregularly directed from the aforesaid causes , and that not a little , as *Gassendus* gives a notable instance of the Island *Elba* in the Mediterranean Sea : but these differences from the general Direction are always signs of the nearness of those Magnetical substances , for the production whereof that Island *Elba* has been famous from all antiquity. Besides , against both *Des Cartes* and *Gilbert*, the change of the Variation, which has been within this Hundred year last past more than 15 gr. at *London* , is an entire Demonstration : tho *Des-Cartes* does not stick to say, that the transportation of Iron from place to place , and the growth of new Iron within the Earth , where there was none before , may be the cause thereof. The same holds likewise against the *Hypothesis* of *Magnetical Fibres* , which *Kircher* maintains,

Now to propose something that may answer the several appearances , and introduce nothing strange in Philosophy , after a great many close thoughts , I can come to no other conclusion than that , *The whole Globe of the Earth is one great Magnet, having Four Magnetical poles, or points of attraction, near each pole of the Equator Two ; and that, in those parts of the World which lye near adjacent to any one of those*

Magnetical poles, the Needle is governed thereby, the nearest pole being always predominant over the more remote. The parts of the Earth wherein these *Magnetical Poles* lie cannot as yet be exactly determined for want of sufficient *Data* to proceed Geometrically: but, as near as Conjecture can reach, I reckon that the *Pole* which is at present nearest to us lies in or near the Meridian of the Lands end of *England* and not above 7 degrees from the Pole *Arctick*. by this *Pole* the Variations in all *Europe*, and *Tartary*, and the *North Sea* are principally governed; tho with regard to that her Northern pole, whose situation is in a Meridian passing about the middle of *California*, and about 15 gr. from the North Pole of the World. to this the Needle has chiefly respect in all the *North America*, and in the Two Oceans on either side thereof, from the *Azores* westwards to *Japan*, and farther. The Two Southern *Poles* are rather farther distant from the South pole of the World. The one about sixteen degrees therefrom is in a Meridian some Twenty degrees to the Westward of *Magellans Straights*; or 95 degrees West from *London*: this commands the Needle in all the *South America*, in the *Pacifick Sea*, and the greatest part of the *Ethiopick Ocean*. The Fourth and last *Pole* seems to have the greatest Power and largest dominions of all, as it is the most remote from the pole of the World, being little less than 20 degrees distant therefrom, in the Meridian which passes through *Hollandia Nova* and the Island *Celebes* about 120 degrees East from *London*; this *Pole* is predominant in the South part of *Africa*, in *Arabia* and the *Red Sea*, in *Persia*, *India* and its Islands, and all over the *Indian Sea* from the Cape of *Good-Hope* Eastwards to the middle of the great South Sea that divides *Asia* from *America*. This seems to be the present disposition of the *Magnetical* vertue throughout the whole Globe of the Earth: it remains to shew how this Hypothesis makes

makes out all the Variations that have been observed of late ; and how it answers to our several remarks drawn from the Table. And first it is plain that (our *European North Pole* being in the Meridian of the Lands end of *England*) all places more Easterly than that will have it on the West side of their Meridian ; and consequently the Needle, respecting it with its Northern point, will have a Westerly variation, which will still be greater as you go to the Eastwards, till you come to some Meridian of *Russia* where it will be greatest, and from thence decrease again. Thus at *Brest* the Variation is but $1\frac{1}{2}$ degrees, at *London* $4\frac{1}{2}$ degrees : but at *Dantzick* 7 degrees West. To the Westward of the Meridian of the Lands end, the Needle ought to have an Easterly variation : were it not that (by approaching the *American Northern Pole*, which lies on the west side of the Meridian, and seems to be of greater force than this other) the Needle is drawn thereby Westwards, so as to counterballance the direction given by the *European Pole*, and to make a small west Variation in the Meridian of the Lands end it self. Yet I suppose that about the Meridian of the Isle *Tercera*, our nearest Pole may so far prevail as to give the Needle a little turn to the East ; though but for a very small space : the Counterballance of those two poles permitting no considerable Variation in all the Eastern parts of the *Atlantick Ocean* ; nor upon the *West Coasts* of *England* and *Ireland*, *France*, *Spain*, and *Barbary*. But to the *Westwards* of the *Azores* the Power of the *American Pole* overcoming that of the *European*, the Needle has chiefly respect thereto ; and turns still more and more towards it as you approach it. Whence it comes to pass that on the Coast of *Virginia*, *New-England*, *New-found land*, and in *Hudsons-straits* the variation is Westward ; that it decreases as you go from thence towards *Europe* ; and that it is less in *Virginia*, and *New-England* than in *New-found Land* and *Hudsons straights*. This *Westerly* vari-

Variation' again decreases, as you pass over the *North America*; and about the Meridian of the middle of *California* the Needle again points due North; and from thence west-wards to *Yedzo* and *Japan* I make no doubt but the Variation is *Easterly*; and half Sea over not less than 15 degrees, if there be any truth in this Hypothesis of mine. Therefore I propose this as a trial, that the whole may be scann'd thereby: and I conceive it will not be hard to know of the *Spaniards* how it is, who so frequently sail through that Ocean, in their return from the *Manilla* Isles. This *East* Variation extends over *Japan*, *Yedzo*, *East-Tartary* and part of *China*; till it meet with the *Westerly*, which is governed by the *European* North Pole, and which I said was greatest somewhere in *Russia*.

Towards the Southern Pole the effect is much the same, only that here the South point of the Needle is attracted. Hence it will follow, that the Variation on the Coast of *Brazil*, at the River of *Plate*, and so on to the *straights* of *Magellan* should be *Easterly* (as in our third remark): if we suppose a *Magnetical Pole* situate about 20 degrees more *Westerly* than the *straights* of *Magellan*. And this *Easterly* Variation doth extend Eastward over the greatest part of the *Ethiopic* Sea, till it be counterpoized by the Vertue of the other Southern Pole: as it is about midway between the Cape of *Good-Hope*, and the Isles of *Tristan d'Acuntia*. From thence Eastwards, the *Asian* South Pole (as I must take the liberty to call it) becoming prevalent, and the South point of the Needle being attracted thereby, there arises a *West* variation very great in quantity and extent, because of the great distance of this *Magnetical Pole* of the World. Hence it is, that in all the *Indian* Sea as far as *Hollandia Nova* and farther there is constantly *west* Variation: at that under the Equator it self it arises to no less than 18. degrees, where tis most. About the Meridian of the Island *Celebes*, being likewise that of this Pole, this

this *Westerly* Variation ceases; and an *Easterly* begins; which reaches according to my Hypothesis to the middle of the *South* Sea between *Zelandia Nova* and *Chili*, leaving room for a small *West-Variation* governed by the *American* South Pole; which I shewed to be in the *Pacifick* Sea, in the Sixth and Seventh remark.

What I have now said, does plainly shew the sufficiency of this Hypothesis for solving the Variations that are at this time observed in the temperate and frigid *Zones*, where the direction of the Needle chiefly depends upon the Counterpoise of the forces of two *Magnetical* Poles of the same nature: and I suppose I have shewn how it comes to pass, that under the same Meridian the Variation should be in one place $29\frac{1}{2}$ *West*, and in another $20\frac{1}{2}$ *East*; as I noted in my ninth remark.

In the *Torrid Zone*, and particularly under the *Equinoctial*, respect must be had to all four Poles, and their positions well considered, otherwise it will not be easy to determine what the Variations shall be: the nearest Pole being always the strongest; yet not so, as not to be counterballanced sometimes by the united forces of two more remote; a notable instance whereof is in our 8th remark, where I took notice, that in sailing from *St. Helena* by the Isle of *Ascension*, to the Equator, on a *NW.* course the Variation is very little *Easterly* and in that whole Tract unalterable. for which I give this reason, that the *South American* Pole (which is considerably the nearest in the aforesaid places,) requiring a great *Easterly* variation is counterpoized by the contrary attraction of the *North-American* and the *Asian-South* Pole; each whereof singly are, in these parts, weaker than the *American-South-pole*; and upon the *NW.* course, the distance from this latter is very little varied; and as you recede from the *Asian-South-pole*, the ballance is still preserved by the access towards the *North-American-Pole*. I mention not in this case the *Eu-*

open North-Pole ; its Meridian being little removed from those of these places ; and of it self requiring the same Variations we here find. After the same manner we might proceed to conclude the Variations in other places under and near the Equator : but I purposely leave it for an exercise to the thoughts of the Serious Reader , who is desired to help his imagination, by having before him a Map or Globe of the Earth ; and to mark thereon the Magnetical Poles in the *Longitudes* and *Latitudes* I assign them.

Thus I hope I have not lost my Pains and Study in this difficult Subject : believing that I have put it past doubt , *That there are in the Earth Four such Magnetial Points or Poles which occasion the great variety and seeming irregularity which is observed in the variations of the Compass.* But to calculate exactly what it is, in any place assigned, is what I dare not yet pretend to ; tho I could wish it were my happiness to be able to oblige the world with so usefull a peice of knowledge. there are difficulties that occur that render the thing as yet not feasible, for first there are a great many observations requisite, which ought to be made at the same time ; not at Sea , but ashore ; with greater care and attention than the generality of Saylor's apply. And besides it remains undetermined in what proportion the attractive power decreases , as you remove from the Pole of a Magnet ; without which it were a vain attempt to go about to calculate. There is yet a further difficultrie , which is the change of the variation, one of the discoveries of this last Century ; which shews , that it will require some Hundreds of years to establish a compleat doctrine of the Magnetical System. From the foregoing Table it should seem , that all the Magnetical Poles had a Motion *Westward* : but if it be so, tis evident that it is not a rotation about the *Axis* of the Earth ; for then the Variations would
continue

continue the 'same', in the same parallel of *Latitude* (the *Longitude* only changed) as much as is the motion of the **Magnetical Poles**, but the contrary is found by **Experiences**; for there is no where in the Latitude of $51\frac{1}{2}$ North, between *England* and *America*, a Variation of 11 degrees East, at this time : as it was once here at *London*, it seems therefore that our *European Pole* is grown nearer the Pole *Arctic* than it was heretofore ; or else that it has lost part of its Vertue. But whether these Magnetical Poles move altogether with one motion, or with several ; whether equally or unqually ; whether circular or Libratory : if circular, about what center ; if Libratory, after what manner ; are secrets as yet utterly unknown to Mankind ; and are reserved for the Industry of future ages.
